EFFIGI
An Efficient Framework For Implementing Global Illumination

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ABSTRACT

This paper presents a rendering framework called EFFIGI (Efficient Framework For Implementing Global Illumination) that uses interfaces which express both geometric concepts and mathematical ones, using object-oriented and component object methods. EFFIGI facilitates the development of new techniques and the implementation of existing ones, by providing a flexible but comprehensive geometric and mathematical architecture. The framework eliminates the need for users to implement an entire system, enabling them to focus only on those areas of particular interest.

Keywords: Rendering Framework, Object-Oriented Design, Global Illumination

1 Introduction

Global illumination deals with the propagation of light through an environment, and is described or modeled in mathematical form by a number of equations. Many rendering architectures have been proposed to support this. These frameworks tend to encapsulate mathematical concepts within physical ones. However it is sometimes desirable to separate these. Firstly the increased visibility of mathematical components make it easier to solve specific problems. Secondly separating the description from the solution contributes to smaller, reusable components, which can be combined and tested with greater ease.

This paper presents a rendering framework called EFFIGI that uses interfaces which express both geometric concepts and mathematical ones, using object-oriented and component object methods. It also handles other concerns that potential users might have, such as object description and scene acceleration.

In Section 2 some background information is provided, and Section 3 discusses the design of our architecture. The implementation of the framework is covered in Section 4 which also demonstrates the construction of various rendering algorithms. Conclusions and future work are presented in Section 5.

2 Previous Work

Many mathematical models are used in image synthesis, the rendering equation [Kajiy86] being one example. These mathematical models are solved by a variety of techniques. By simplifying these, easier and faster methods of solution may be found. For instance the radiosity equation [Cohen88] is a simplified form of the rendering equation that can be solved using finite element methods such as Galerkin [Zatz93] or point colocation [Cohen93] methods. However, this simplification limits the types of environment that can be described. More general descriptions like the rendering equation (see Figure 1) need more general methods of solution such as Monte Carlo integration. Some of the methods come directly from numerical techniques such as Metropolis [Veach97] or Galerkin methods. Others such as bi-directional path tracing [Veach94, Lafor93] are derived from the nature of ray paths. Most methods, however have the common property that they are described using mathematics.

Various architectures have been devised to handle this situation. Some have been tied to a specific technique [Cook87, Kirk88, Shirl91, Ward88, Walte97]. Others have been general enough to allow a variety of rendering techniques. The Cornel "testbed for image synthesis" [Trumb91] is a toolbox that can be used to construct a rendering package but is not object-oriented. Glassners "Spectrum" architecture [Glass91] is an object-oriented framework based on signal processing. The Vision system [Slusa95] is capable of most rendering methods as is the RenderPark system [Bekae]. In Section 5.1 of this paper we compare the last two frameworks with ours.

3 Design

The design of the EFFIGI framework is motivated by several key factors. It is fully object-oriented, thus enabling increased flexibility and code re-use. The abstractions are based not just on physical concepts such as radiance and radiosity but also on their mathematical foundations. In order to make development easy there is a means of testing components. The time taken to generate a picture is very important, so speed has been taken into consideration throughout all phases of the design process.

3.1 Object Oriented Design

Object oriented techniques are used to decompose the rendering process into simple manageable parts. The interfaces that arise from this fit into four main groups:

- *mathematical* for sample generation, function evaluation and integration.
- *scene and object management* for ray queries, meshing and path generation.
- *data storage* to support data structures such as linked lists, k-d trees [Bentl75] and vectors.
- *setup* for object initialisation and setup.

Within each of these groups, various sets of interfaces are provided. For a full list of interfaces see Table 1.

Math	Scene	Setup	Data
ISampler	IIntersect	IRenderer	IContainer
IFunction	IShape	IInterface	IVector
IIntegrator	IMesh	IInitialise	ITree
IGenerator	IRay		IList
IRootFinder	IlluminationMap		
IWarp	IPathGenerator		
	IEvent		
	IEventStore		

Table 1: Interfaces in Framework

$$L(\vec{\omega_i}, x) = \underbrace{L_\epsilon(\vec{\omega_i}, x)}_{IFunction} + \underbrace{\overbrace{\int_\Omega \overbrace{\rho(\vec{\omega_i}, x, \vec{\omega_o})}^{IFunction} L(\vec{\omega_i}, x) \cos\theta \, d\vec{\omega}}^{IFunction}}_{IIntegrator \text{ and } IFunction}$$

Figure 1: The Rendering Equation

3.2 Mathematical Foundation

The abstraction of mathematical concepts provides generic access to various algorithms, allowing a "pick-and-mix" approach to choosing a suitable technique. This abstraction is important in image synthesis, because many models use mathematically-based methods. For example, the light propagation model used in rendering utilises sampling and integration. EFFIGI provides explicit support for these ideas, by translating concepts such as functions, integration and sampling into interfaces. The learning curve for the users of such a framework will not be steep, since such people are typically well-aware of the mathematical ideas involved.

The most common interfaces used are the *IIntegrator* and *IFunction* interfaces. These are usually used to represent the various parts of our image synthesis model. The *IFunction* interface can be used to represent surface reflection models or to evaluate ray paths. When used by an *IIntegrator* the total light reaching a point can be estimated. Figure 1 shows how this can be encapsulated within another function interface to represent the rendering equation. The parameters of the inner most *function* represent the direction (θ, ϕ) that the ray goes when it strikes a surface as in the case shown. They are equally likely to represent a surface and coordinates on it (s, u, v), if a surface form of the rendering equation is used. This configuration represents a distributed ray tracer since the function is recursive. A more efficient implementation would expand the inner function and use it to represent n bounces, where n is the first parameter, thus creating a path tracer. To allow this the function interface provides methods which disclose this information.

3.3 Testing Facilities

An important feature of the framework is its facility to test components for compliance with a given specification. For instance, a Bi-directional Scattering Distribution Function(BSDF) should be physically plausible; a scene acceleration scheme should support all the required features, and provide the same intersection information as another scheme given the same data; an interface should produce valid responses to a specified set of inputs. Previously, it was necessary to run components with a complete setup, and then attempt to identify artefacts in the output. Now users can run the testing components with default setups, allowing rapid identification and location of errors. This speeds up the development process significantly. It is also possible for users to quickly ensure that the interfaces provided can support any new components they may wish to add to the framework.

4 Implementation

The *Component Object Model* [Krugl97, Roger97] was used in EFFIGI to provide a consistent interface for creation and destruction of components, and to provide Run Time Type Information (RTTI). It allows the use of shared libraries or DLLs[1]

[1] In UNIX they are called shared libraries in Windows dynamic link libraries or DLL's. These enable the sharing of compiled code by allowing libraries to be dynamically loaded at runtime.

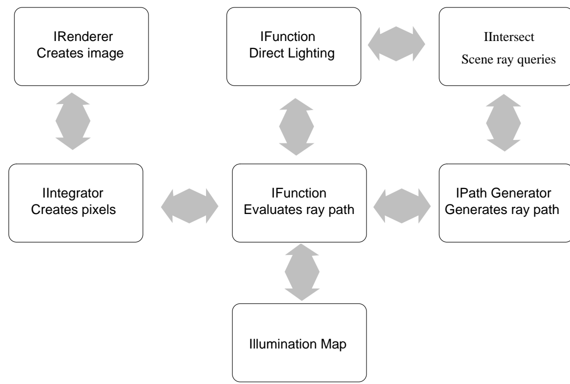

Figure 2: Path Tracer Configuration

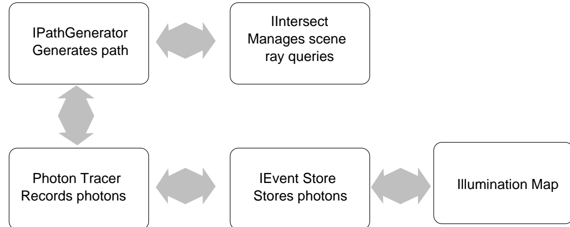

Figure 3: Photon Tracer Configuration

which gives our framework the ability to have a "plug-in" style component architecture without any extra work by the programmer.
To date, EFFIGI has been used to implement many of the major rendering methods in use today. We now have a package, which can be configured to use a multitude of different techniques with ease. What follows are some examples that illustrate some typical uses of the framework.

4.1 Path Tracer

The path tracer [Kajiy86, Dutre94] is constructed from a few basic components as shown in Figure 2. Direct Lighting is achieved using an *IFunction* interface which evaluates rays from the light to the point in question. This is then called from inside the path evaluator. Each box represents a component which can be substituted at run time, and thus a variety of configurations are possible. The picture shown in Figure 4 was rendered using a VEGAS [Lepag80] style integrator with a

Figure 4: Path Tracer

directional path generator and a surface to surface direct lighting function.

4.2 Photon Map

A Photon Map [Jense96] is a preprocess which is used to create illumination maps (see Figure 3). These can be used with the path tracer configuration just described by using a modified path evaluator. These path evaluators query the illumination maps at a given point, obtaining an estimate of the incoming radiance at that point. The photon generator can use all the samplers and warping schemes just like a path tracer, storing photons using an *IEventStore* interface. The component used to store the photons can use a k-d tree, quad tree or any other suitable structure, and might also directly support an *IIlluminationMap* interface. Alternatively, it can provide some facility to convert it to a suitable structure for some other component which would provide the illumination map during the rendering phase. Figure 5 shows a Photon Map used in conjunction with a path tracer, which in turn uses a Mean Sample Monte Carlo integrator [Kalos86] with a random sampler. The photons

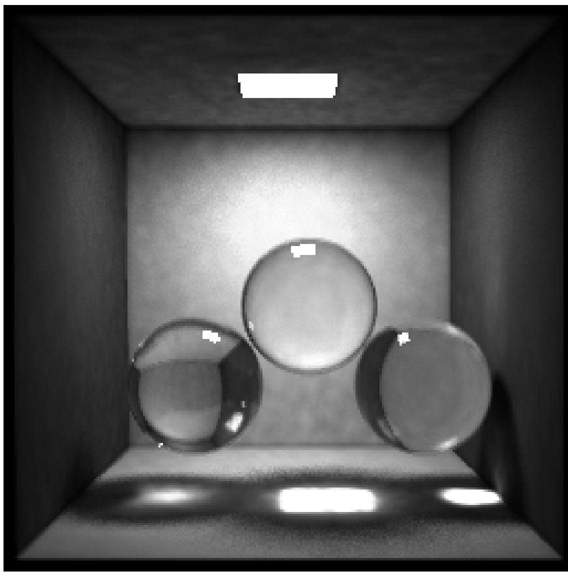

Figure 5: Photon Tracer

Figure 6: Irradiance Map

were generated from the light source using a Metropolis sampler which sampled the emission function $L_e(u, v, \lambda, \vec{\omega})$ of the light source to generate a sample set.

4.3 Irradiance Map

An Irradiance Map [Ward88] is a modified path evaluator which caches radiance information in an illumination map, also using an *IEventStore* interface. Unlike the photon map it is not a preprocess but a modified path evaluator (see Figure 7). Shown in Figure 6 is a picture generated using an Irradiance Map style path evaluator and a Mean Sample Monte Carlo integrator using a Hammersly [Press96] quasi-random sample set.

4.4 Radiosity

Radiosity [Cohen93] is implemented as a preprocess, as in the Photon Map method. Similarly radiosity is stored in a component, this time using the *IMesh* interface. This interface supports the ideas of patches from which form factors can be calculated and radiosity stored. The component may support an *IlluminationMap* interface, or it may provide the ability to output a texture, or something that can be used by an illumination map component. The form factor is calculated using a component that supports an *IFunction* interface that takes two surfaces as properties, the parameters of which are the (u, v) surface coordinates on each surface. This enables the use of various integration schemes (see Figure 8 for the configuration used). Figure 9 is a radiosity illumination map rendered using a Mean Sample integrator with random sampling. The radiosity structure used a Metropolis sampler to integrate the form factor function using the visibility function as a basis for the probability density function(pdf).

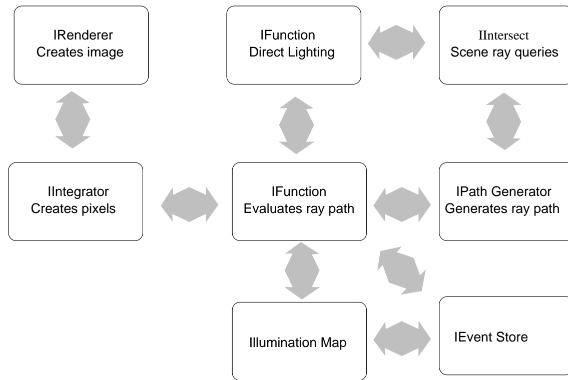

Figure 7: Irradiance Map Configuration

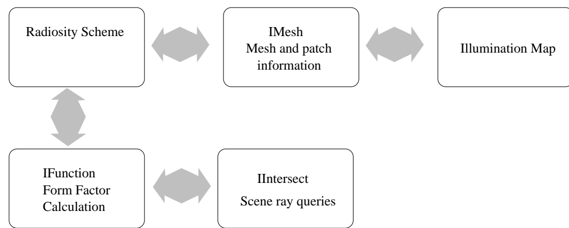

Figure 8: Radiosity Configuration

5 Conclusions and Future Work

EFFIGI has been successfully used in the implementation of many of the latest techniques in image synthesis. It is extremely flexible and provides a means of easy augmentation using both source code and binary DLL's. The use of interfaces in the framework allows easy extension of many older methods without having to reimplement them. Since all the modules can be provided as a DLL, only the modules actually referenced are loaded thus reducing the memory footprint of the system.

Implementers are also allowed to experiment with various ideas (for example sampling schemes) without having to alter any code. If the code is written in a generic way it can be used with many of the other components, thus extending the entire system. This encourages the user to break up any objects they create into many reusable parts so that they can be used with the other elements of the system. This has resulted in greater flexibility, more code reuse and a powerful rendering environment.

5.1 Comparisons

Although comparing frameworks is diffucult, the following attempts to highlight some of the differences between our framework and two others introduced in Section 2 which share similar objectives.

Figure 9: Radiosity

RenderPark is an object oriented rendering framework which is freely available to the public. Both it and EFFIGI divide the set of rendering techniques into view dependent or view independent, and this dictates how they are implemented. The strength of RenderPark is its extensive suite of Radiosity algorithms. However, it lacks the mathematical basis of EFFIGI, meaning that integration and other mathematical methods cannot be changed easily. In addition, scene acceleration has been implemented using utility functions that do not support any common form of interface.

Vision is another object-oriented rendering framework which, like EFFIGI, derives its geometry subsystem from the Ray Tracing Kernel [Kirk88]. Vision uses a physically based object-oriented abstraction of the rendering process, and can render physically correct as well as nonphysical systems. However, it specifies fixed mathematical models for some interfaces that cannot be changed by the programmer. In addition, the sampling interfaces have been fragmented for use with different techniques.

Table 2 presents a summary of the features in the frameworks: Effigi(E), Visoin(V) and RenderPark(RP).

features	*E*	*V*	*RP*
Physically based	yes	yes	yes
Radiosity	PR	many	many
Object Oriented	yes	yes	mostly
Plug-ins	yes	no	no
Mathematical basis	yes	no	no
Object Model	COM	CORBA	no

Table 2: Framework Features

5.2 Future Work

To date the framework supports an extensive set of ray-based techniques, but only one Radiosity method. In the future this will be extended to many of the other radiosity methods. This will probably add more interfaces as more common ground between each technique is exposed. Another extension is the support of parallel implementations such as data- distributed methods for large data sets. Hopefully this can be hidden in scene type components. As yet we are not sure if the parallel nature of various algorithms needs to be made explicit, or if it can be hidden behind the current set of interfaces. If this is the case all the current methods would work seamlessly with parallel methods. Finally, it is proposed to provide support for more numerical methods, especially for the common tasks of integration and sampling which are useful in all areas of rendering.

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